with the process, the performance of refrigeration equipment was assessed using the developed structural and parametric identification of a fuzzy model, as well as through the use of genetic algorithms and artificial neural networks, the results of which allow us to investigate and establish the relationship between the parameters of the freezing process in refrigeration chambers of an industrial refrigerator and defects (failures), which are the causes of emergencies and accidents.

***Key words**: reliability, emergency situations, risk minimization, identification, cold supply, ammonia compressor machines, neuro-fuzzy control, intelligent system.*

DOI : 10.33274/2079-4827-2022-45-2-71-77
UDC [631.576:582.711.714]:(631.362:502.21-027.236-049.34)

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INCREASING RESOURCE SAVING AND OPERATIONAL EFFICIENCY OF APPLE SORTING DEVICE

УДК [631.576:582.711.714]:(631.362:502.21-027.236-049.34)

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ПІДВИЩЕННЯ РЕСУРСОЗБЕРЕЖЕННЯ ТА ЕФЕКТИВНОСТІ ФУНКЦІОНУВАННЯ ПРИСТРОЮ ДЛЯ СОРТУВАННЯ ЯБЛУК РІЗНОГО РІЗНОВИДУ

***Objective**. The purpose of the article is to increase the resource saving and efficiency of the device for sorting apples of various varieties.*

***Methods**. In the work for sorting apples, namely varieties Golden and Granny Smith, methods for finding singular points were used: the Harris method, the SURF method, the SIFT method, the FAST method, and others.*

***Results**. It is noted that in modern conditions, the issue of improving food production processes and equipment is extremely relevant. It is possible to improve the process of sorting apples by using a system of tracking objects in the flow through the identification of contours of objects, namely video surveillance through unique special points. Currently, there are a large number of algorithms for selecting special points of an image, which convey information about certain features of the image. On the basis of complex analysis, it is considered that during the processing of the upper segment of the frame $f_\alpha(x, y, t)$, the outline of the apple and its visual characteristics are determined: size (d), weight (m), color (g). At this stage special points and their descriptors are defined. Unique descriptors of singular points related to the selected object are memorized and in the future according to their location in the lower fragment of the frame $f_\beta(x, y, t)$ are evaluated and subject to selection. Attention is focused on the fact that due to the limited speed of the executive sorting mechanism, it is important to estimate the distances between groups of objects located close to each other. The method of multi-criteria selection*

Надійшла до редакції 17.10.2022 р.

involves extracting the apples with the worst indicators from a set of options that need to be selected from the general stream. Apples whose indicators meet the specified conditions (size (d), weight (m), color (g)) are removed from the general flow and sent for further processing in the food industry. In order to increase the efficiency of apple sorting, it is proposed to recognize the contours of objects when they appear in the frame and then conduct video surveillance of unique special points of the image. To meet the condition of reliability, it was established that the threshold for determining the value of mutual correlation should not be less than 0.985. A promising direction of further research is the analysis of image processing methods of video streams to improve the quality of recognition by eliminating distortions caused by the movement of the stream of objects during video camera observation.

***Key words**: sorting, automation, sorting device, technological processes, apples, methods for finding singular points, video surveillance.*

Formulation of the problem. Today, the problems of improving the processes and apparatuses of food production are becoming extremely important. Labor productivity at domestic food production enterprises is 2–4 times lower than at similar enterprises in the developed countries of the world, because about 50% of labor-intensive operations are performed manually and only 20% of existing equipment operates in automatic mode [1]. The quality of products and the costs of their production largely depend on the efficiency of technologies, processes and apparatus, the level of their mechanization and automation, which ensures the intensification of the development of the food industry.

Analysis of recent research and publications. One of the main operations of post-harvest processing of apples is their quality sorting. External injuries, such as bruises, depressions, burns, reduce the commercial quality of the fruit raw material, reduce the shelf life. Recently, image processing electronics have been improved to solve this problem, and recognition systems for sorters are becoming increasingly important.

When detecting and recognizing apples, it is advisable to use the characteristic features of images [2]: geometric, radiometric, texture, topological, dynamic, temporal. Currently, there are a large number of algorithms for selecting key points in images that transmit information about certain features of the image.

According to the Harris method, the singular points are the corner points of the brightness difference [3]. The application of this method involves the performance of a sufficient resource-intensive operation of calculating the matrix eigenvalues. Also, as noted in [2], the application of the method is inexpedient under conditions of image scaling and rotation, which are typical for images of objects moving in a stream on conveyor lines.

Considering the SURF [4] method, the search for singular points is based on the calculation of the Hessian matrix. In addition, as shown in [4] for images with a uniform texture, which include images of objects, the SURF method demonstrates a low accuracy of personal point comparisons. The FAST (Features from Accelerated Test) method proposed in [5] involves the construction of decision trees for classifying pixels in a stream image.

The SIFT method proposed in [6] is completely invariant to scaling, rotation and translation, and also partially to affine transformations and changes in illumination. Characteristic features are distinguished at different image scales by filtering, which makes it possible to find blurry image gradients with different local orientations.

According to the SURF method [4], the search for singular points is based on the calculation of the Hessian matrix, as a convolution of the pixel values of the image of the flow object with the Gaussian Laplacian. It should be noted that the Hessian is rotation invariant but not scale invariant. In addition, as shown in [2] for images with a uniform texture, which include images of objects, the SURF method demonstrates a low accuracy of matching singular points.

Objective of the article is to increase resource saving and efficiency of the device for sorting apples.

Presentation of the main study material. Presentation of the main study material. It is possible to improve the process of sorting apples through the use of an object tracking system in the stream. On apple sorting devices, it is advisable to recognize the contours of objects when they appear in the frame, and then their video surveillance of unique special points of the image. To do this, the

frame of the video stream is divided by a conditional horizontal line in accordance with fig. 1, passing through the line with the MS index into two fragments.

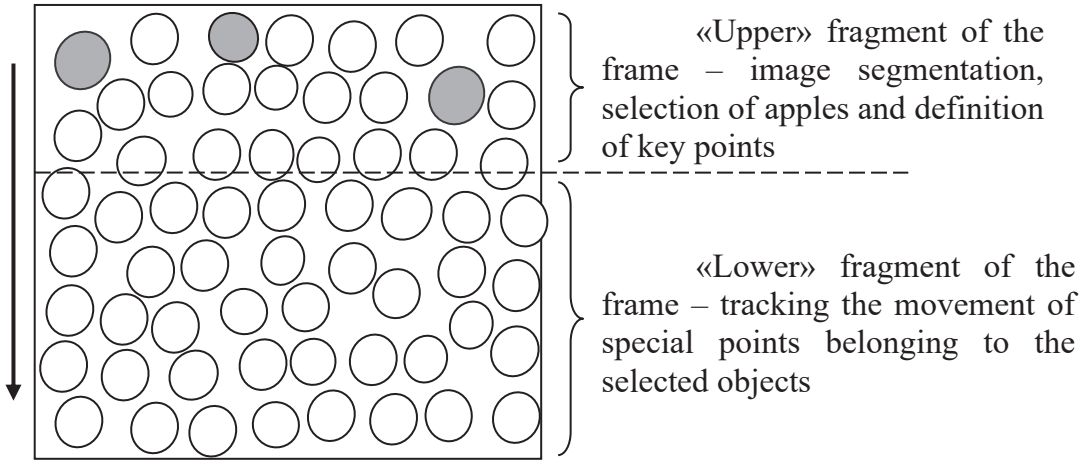

Figure 1 — Processing principle of apple flow image

$$f(x,y,t) \Rightarrow \left(f_{\alpha}\left(x,y,t\right) \mid x = \overline{0, M_S - 1} \right) \cup$$
$$\cup \left(f_{\beta}\left(x,y,t\right) \mid x = \overline{M_S, M - 1} \right), y = \overline{0, N - 1} \quad (1)$$

The apples on the conveyor belt will move from the top of the frame to the bottom.

When processing the upper fragment of the frame $f_{\alpha}(x, y, t)$ the contours of apples and their visual characteristics are determined: size (d), weight (m), color (g). At this stage, the search for singular points in the entire image and the calculation of their descriptors are performed. The unique descriptors of those singular points that belong to the selected objects are stored, and in the future, according to their location in the lower fragment of the frame $f_{\beta}(x, y, t)$, the location of the corresponding apples to be selected is estimated.

The limited speed of the executive sorting mechanism does not allow dumping apples located close enough on the same line in the direction of the conveyor line. Therefore, the distance between groups of closely spaced objects is estimated and the method of multi-criteria selection is made, apples with the worst indicators are excluded from the set of options to be selected from the general flow: minimum size, improper external condition and color. It is derived from the general flow of apples, which can be sent to the industrial processing according to the following characteristics: size (d), weight (m), color (g).

If there are, in the general case N objects from which the choice is made, we have the following characteristics [6]:

$$\overline{d} = \left\{ d_i \middle| 1...N \right\}, \ \overline{m} = \left\{ m_i \middle| 1...N \right\}, \ \overline{g} = \left\{ g_i \middle| 1...N \right\}.$$

The object with index i includes a set of characteristics with the same indices $\Theta_i = \left\{ d_i, m_i, g_i \right\}$. In the general case, when choosing one element from a set $\Theta = \{\Theta i | 1...N\}$, it is necessary to ensure the maximum approximation of the values of the element's characteristics to some given values of the «ideal sample» $\Theta^* = \left\{ d^*, m^*, g^* \right\}$.

At the initial stage, certain areas of the image containing apples are scanned according to the specified characteristics in accordance with fig. 2.

The following designations are accepted: E — is the original image, Ln — is the set of points of the observed image fragments; Hn, Gn — are the set of points from the flow of apples and background points in the observed image fragments. In this case, the centers of the image fragments are located at a point corresponding to the predicted coordinates of the given objects $(\lambda_{hx}(n), \lambda_{hy}(n))$.

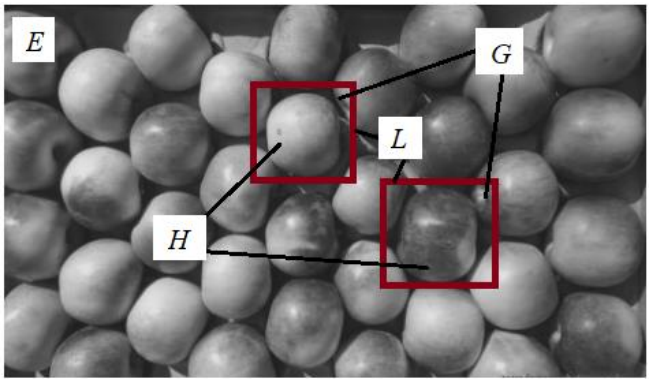

Figure 2 – Fragments of the image of the flow of apples containing the desired objects

Taking into account the noise introduced by the video camera, the model for observing a sequence of images of a stream of apples [7].

$$L(n) = R(n)H(n) + (1 - R(n)\ G(n) + \Xi(n) \quad (2)$$

where $L(n)$ — is the observed image presented as a vector; $H(n)$ — is the vector corresponding to the image Hn; $G(n)$ — is the vector corresponding to the background image Gn; $X(n)$ — noise vector; $R(n)$ — is a square diagonal matrix whose diagonal elements are $r_n = \{1,0\}$; 1 is the identity matrix.

To solve the problem associated with determining the singular points of apple images, the dependences of the basic SIFT algorithm and its modifications DSIFT [6, 9, 10] and FastDSIFT [8] were studied. It has been established that the error in determining descriptors using the FastDSIFT method for different values of the number (bin) of the descriptor exceeds the similar DSIFT indicator according to fig. 3.

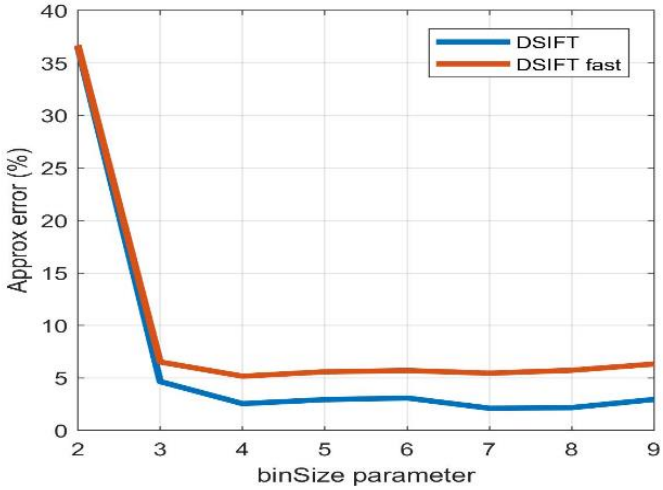

Figure 3 – The magnitude of the error definition of image fragment descriptors of the stream of objects

The use of modifications of the FastDSIFT method makes it possible to significantly increase the speed of work of departments to determine the basic SIFT method, the speed of which is assumed to be one in accordance with fig. 4.

As a result of the study of the SIFT algorithms and its modifications DSIFT and FastDSIFT for solving the problem of determining the singular points of images, it was found that the error in determining descriptors using the FastDSIFT method for different values of the number of regions (bin) of the descriptor exceeds that of DSIFT slightly. At the same time, the use of the FastDSIFT method made it possible to significantly increase the speed of the descriptor determination subsystem, which allows us to conclude that it is advisable to use it in the food industry. Since, in this case, the more important factor is the accuracy of the video tracking system for

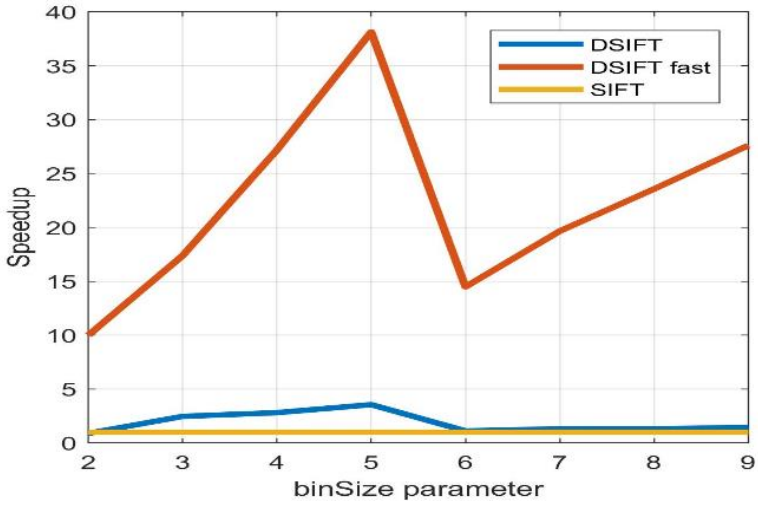

Figure 4 — Increasing the speed of the subsystem for determining the descriptors of a fragment of an image stream of objects

objects in the stream, the value of the binSize parameter was chosen to be 4, which corresponds to an increase in the speed of work by an average of 26–27 times.

Conclusions. Therefore, the apple sorting process can be improved by applying an object tracking system in the stream. On apple sorting devices, it is advisable to recognize the contours of objects when they appear in the frame, and then their video surveillance of unique special points of the image. When processing the upper fragment of the frame $f_{\alpha}(x, y, t)$, the contours of apples and their visual characteristics are determined: size (d), weight (m), color (g), special points are searched for throughout the image and their descriptors are calculated. The unique descriptors of those singular points that belong to the selected objects are stored, and in the future, according to their location in the lower fragment of the frame $f_{\beta}(x, y, t)$, the location of the corresponding apples to be selected is estimated.

To comply with the condition of detection authenticity, it is established that the threshold for the cross-correlation value must have a value of at least 0.985. Promising directions for the subsequent stages of research are methods for processing images of a video stream in order to improve the quality of recognition by eliminating distortions caused by the movement of a stream of video camera objects.

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Мета. *Метою статті є підвищення ресурсозбереження та ефективності функціонування пристрою для сортування яблук різного різновиду.*

Методи. *У роботі для сортування яблук різного різновиду, а саме сортів яблук Golden і Granny Smith, було застосовано методи пошук особливих точок: метод Харріса, метод SURF, метод SIFT, метод FAST та інші.*

Результати. *Зазначено, що в сучасних умовах надзвичайно актуальним постає питання удосконалення процесів і обладнання харчових виробництв. Покращити процес сортування яблук можливо за допомогою застосування системи відстеження об'єктів у потоці через ідентифікацію контурів об'єктів, а саме відеоспостереженням через унікальні особливі точки. В даний час існує велика кількість алгоритмів виділення особливих точок зображення, які передають інформацію про певні особливості зображення. На основі комплексного аналізу вважається, що під час оброки верхнього сегмента кадру* $f_{\alpha}(x, y, t)$ *визначається контур яблука та його візуальні характеристики: розмір (d), вага (m), колір (g). На цьому етапі знахо-*

дяться особливі точки та обчислюються їхні дескриптори. Унікальні дескриптори особливих точок, що належать до вибраного об'єкта запам'ятовуються і надалі згідно їх розташування в нижньому фрагменті кадру $f_{\beta}(x, y, t)$ оцінюється та підлягають відбору. Акцентується увага на тому, що у зв'язку з обмеженою швидкістю виконавчого сортувального механізму, важливою є оцінка відстаней між групами об'єктів, розташованих близько один до одного. Методом багатокритерійного вибору здійснюється вилучення яблук з найгіршими показниками із множини варіантів, які потрібно вибрати із загального потоку. Яблука, показники яких відповідають заданим умовам (розмір (d), вага (m), колір (g)) вилучаються із загального потоку і відправляються для подальшої переробки у харчовій промисловості. Запропоновано для підвищення ефективності пристрою для сортування яблук розпізнавати контури об'єктів, коли вони з'являються у кадрі і надалі проводити відеоспостереження за унікальними особливими точками зображення. Для дотримання умови достовірності було встановлено, що поріг для визначення значення взаємної кореляції має бути щонайменше 0,985. Перспективним напрямком подальших досліджень є аналіз методів обробки зображень відеопотоків для підвищення якості розпізнавання за рахунок усунення спотворень викликаних рухом потоку об'єктів у процесі спостереження відеокамерою.

***Ключові слова**: сортування, автоматизація, пристрій сортування, технологічні процеси, яблука, методи пошук особливих точок, відеоспостереження.*